# HEAVY MESONS

Studies of interactions and lifetime of the positive heavy meson and interactions, lifetime and decay modes of the negative heavy meson

by

SIGWARD NILSSON

UPPSALA 1958
ALMQVIST & WIKSELLS BOKTRYCKERI AB

# HEAVY MESONS

Studies of interactions and lifetime of the positive heavy meson and interactions, lifetime and decay modes of the negative heavy meson

INAUGURAL DISSERTATION

by

SIGWARD NILSSON
Fil. lic., Östg.

By due permission of the Faculty of Science
of the University of Uppsala to be publicly discussed in English
in the lecture hall of the Institute of Physics on
October 18, 1958, at 10 a.m., for the
degree of Doctor of Philosophy

UPPSALA 1958
ALMQVIST & WIKSELLS BOKTRYCKERI AB

# Charged Heavy Mesons

Elementary Particle Physics has emerged as a special branch of Physics in recent years. If we confine ourselves to the history of the unstable particles heavier than the $\pi$-meson two periods can be distinguished.

In the years 1947–1955 most of the elementary particles and their decay modes were discovered in cloud chambers and photographic emulsions exposed to cosmic radiation.

In 1955 focussed beams of $K$-particles and antiprotons became available at the big accelerators. From now on cosmic radiation loses its importance as a source producing unstable, heavy particles, except at the very high energies. Practically all new discoveries concerning $K$-mesons, hyperons, hyperfragments and antiprotons have since then been made by means of machine produced particles.

The first problems to be solved by using the machine produced $K$-mesons were the masses of the different decay modes of the positive $K$-particle, its mean lifetime and the spin and parity character of the $\tau^+$-meson.

The next phase in the development consisted of large scale investigations of the interaction properties of the positive $K$-meson. The present thesis starts at this point.

The investigations concerning the negative $K$-particle were at first hampered by the low intensity and high background contamination of the beams. A separated $K^-$-beam of reasonable intensity was not available until the end of 1956.

The present thesis reports on the interactions in flight and mean lifetime of the positive $K$-meson and the interactions in flight, the decay modes, the mean lifetime and the absorption at rest by bound protons of the negative $K$-meson. The experiments have been performed in stacks of nuclear emulsions exposed to the $K^+$-beam (summer 1955) and the $K^-$-beam (summer and end of 1956) at the Bevatron, Berkeley, California. The thesis contains the following papers:

I. B. Bhowmik, D. Evans, S. Nilsson, D. J. Prowse, F. Andersson, D. Keefe, A. Kernan and J. Losty, The Interactions of Positive $K$-mesons with Nuclei in Photographic Emulsion at Energies in the Region 0–130 MeV. *Nuovo Cim., 6,* 440 (1957).

II. B. Bhowmik, D. Evans, S. Nilsson, D. J. Prowse, F. Andersson, D. Keefe, A. Kernan, N. N. Biswas, M. Ceccarelli, P. Waloschek, J. E. Hooper, M. Grilli and L. Guerriero, The Lifetime of Positive Heavy Mesons. *Nuovo Cim., 5,* 994 (1957).

III. S. Nilsson and Å. Frisk, Interactions in Flight of Negative Heavy Mesons. *Ark. f. Fysik, 14*, 277 (1958).

IV. S. Nilsson and Å. Frisk, Decay Modes and Lifetime of Negative Heavy Mesons. *Ark. f. Fysik, 14*, 293 (1958).

V. S. Nilsson, A Decay of A Negative $\tau'$. *Nucl. Physics, 3*, 364 (1957).

VI. S. Nilsson and Å. Frisk, Emission of Charged $\Sigma + \pi$ from $K^-$-proton Capture in Nuclear Emulsions. *Ark. f. Fysik, 14*, 303 (1958).

VII. A. G. Ekspong and S. Nilsson, Protonic $\Sigma$-decay with an Associated Electron Pair. *Phys. Rev., Letters, 1*, 36 (1958).

The contents of the papers can be summarized as follows:

I. 148 m of $K^+$ track have been followed in an unbiased way and 109 inelastic interactions with emulsion nuclei found. In addition 3 $K^+$-proton scattering events have been found and numerous cases of elastic scattering from emulsion nuclei. The differential cross section for the elastic scattering has been plotted for three energy intervals and the results compared with those predicted by the optical model for various nuclear potential well depths. The variation of cross section with energy for the inelastic events is found to be consistent with isotropy if the Pauli Exclusion Principle is taken into account and the best fit for the experimental points is obtained for a repulsive potential of 20 MeV. The inelastic events have been analysed on the basis of the statistical model of the nucleus and an attempt has also been made to obtain from the experimental data the angular distribution in the C.M. system of the $K$-nucleon cross section. On any reasonable assumption this appears to be peaked backwards. These data also demand a repulsive potential of $\sim 20$ MeV. The value of the average $K$-nucleon cross section within nuclear matter for meson energies between 40 and 120 MeV is 4 mb/nucleon; allowing for the events forbidden by the exclusion principle this implies a cross-section of 6 mb on a free nucleon. Taking $\sigma_p = (14 \pm 3)$ mb, it follows that $\sigma_n = (2 \pm 2)$ mb. The ratio of charge exchange events to non-charge exchange events is $0.20 \pm 0.07$—the value expected in the limit of vanishingly small interaction in the $T = 0$ state.

II. Over two hundred examples of the decay in flight of positive heavy mesons produced at the Bevatron have been observed in the photographic emulsions, and from these the lifetime of the particles has been estimated. The lifetime averaged over all modes of decay is found to be $1.35^{+0.16}_{-0.13} \times 10^{-8}$ s. The effect of experimental biases is discussed, and the final result is compared with that of other authors.

III. 41 m of $K^-$ track length have been followed in the energy interval 0–140 MeV. 208 interactions in flight are analysed to yield the total cross section per nucleus in emulsion $\sigma = 780 \pm 60$ mb. The corresponding average total nucleon cross section in nuclear matter is calculated to be $\sigma = 80 \pm 15$ mb. The mean free path $\lambda = 0.95 \times$ $\times 10^{-13}$ cm implies a large absorptive potential $\sim 60$ MeV. The derived limits on the free neutron cross sections do not contradict the assumption that charge independence holds in the absorption and scattering processes. The differential cross section for

elastic scattering between 5°–30° is given. An attractive $K^-$-nuclear potential is inferred from the percentage of reemerging $K^-$-mesons.

IV. 21 events representing possible decays of a negative $K$-meson in emulsion have been measured in order to get the relative abundances of different decay modes, an estimate of the contamination from nuclear reactions and a determination of the mean lifetime. Events consistent with $\tau^-$, $K^-_{\mu 2}$, $K^-_{\mu 3}$, $K^-_{\pi 2}$, $K'^-_{\pi 3}$, and $K^-_{\beta 3}$ were found. The ratio $\tau^-/K_L + \tau^- = 3/20 = 0.15$ and $K_{\pi 2}/K_{\mu 2} = 3/7 = 0.43$. The percentage of nuclear reactions among the events with one charged secondary was $\sim 20\,\%$. The mean lifetime $\tau_{K^-} = (1.50^{+0.45}_{-0.30}) \times 10^{-8}$ s. Three $\tau^-$ are reported and from one $\tau^-$ the mass of the negative $\tau$-meson was $m_\tau = 494.4 \pm 1.2$ MeV.

V. An event consistent with the decay of a negative $\tau'$ is reported.

VI. A 100 two-prong stars with emission of one charged baryon and one $\pi$-meson only from $K^-$ capture in nuclear emulsions have been analysed. 23 $\Sigma^+ + \pi^-$, 30 $\Sigma^- + \pi^+$, and 9 $\Sigma^\pm + \pi^\mp$ events were compatible with captures on bound and free protons. A comparison between the experimental and expected hyperon energy distribution, using a degenerate Fermi gas model of the nucleus, gives a best fit for an attractive real $\Sigma$-nuclear potential of 25 MeV. An average Coulomb potential of the capturing nucleus of $8 \pm 2$ MeV is deduced, implying that $\sim 40\,\%$ of the captures occur on light nuclei and $\sim 60\,\%$ on heavy nuclei. The fraction of zero prong $\Sigma^-$-stars is $0.66 \pm 0.10$. The $\Sigma^-$-mass is found to be $m_{\Sigma^-} = 1196.7 \pm 0.6$ MeV from three $K^-$ captures on free protons.

VII. An unusual example of protonic $\Sigma$-decay with an associated electron pair is reported. The event is direct evidence of the $\pi^0$ in the $\Sigma \to p$ decay but the explanation in terms of the alternative Dalitz mode of decay of the $\pi^0$ is not entirely satisfactory. Various possibilities are considered.

## ACKNOWLEDGEMENTS

The investigation of the positive $K$-meson was carried out at H. H. Wills Physical Laboratories, Bristol, England, where I was introduced into this field of research. The $K^-$-analysis was performed at the Institute of Physics, University of Uppsala.

The hospitality offered by Professor C. F. Powell during my stay in Bristol is gratefully acknowledged. I should like to thank my colleagues, in particular Dr. D. J. Prowse, Dr. D. Evans and Dr. B. Bhowmik, for illuminating discussions. The inspiring spirit of the group will long be remembered.

Professor Kai Siegbahn has put excellent facilities at the disposal of the emulsion group at the University of Uppsala. I am very grateful for his interest and support.

I am greatly indebted to my friend and teacher Dr. G. Ekspong. Without his unselfish support and encouragement this thesis would not have been possible. I also thank Professor Per Ohlin and the friends of the Institute of Physics, Uppsala.

Thanks are due to my co-author Fil. mag. Åke Frisk for his able work.

Thanks are also due to our team of scanners, Mrs. Ingeborg Nilsson, Miss Inger Durén, Mrs. Siri Eklund, Miss Berit Lundqvist and Miss Veronica Braun.

The kind cooperation of Dr. E. J. Lofgren and the Bevatron Crew is gratefully acknowledged.

I take this opportunity of expressing my gratitude to the Swedish Atomic Energy Commission for financial support during my stay in Bristol. Thanks are also due to Hermods, Malmö, for a grant which made it possible for me to visit all important emulsion groups in Europe in 1957.

This work has been partly sponsored by ARDC through its European office.

Uppsala, August 1958

*Sigward Nilsson*

Institute of Physics,
University of Uppsala